How do we visualize interfaces between very thin layers?

3-Dimensional Atom Probe Studies of Thin Film Multilayers

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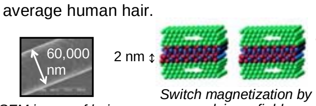
Abstract

Thin film multilayers are used in a number of household electronic devices:

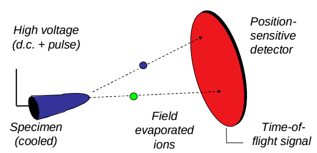
They consist of a sequence of very thin layers, each of which can be 50,000 times thinner than the average human hair.



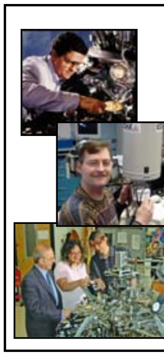
How well the device operates is linked to the:

- chemistry and structure of layer interfaces
- chemistry and structure within layers
- layer thicknesses

Atom probe allows us to "see" atom by atom in 3-dimensions both structure and chemistry at very high magnifications.



Sample Preparation Methods



- The multilayers are grown on Si substrates using high vacuum **sputtering techniques** (NIST)
- We use a **focused ion beam** to make fine needles from our samples (Electron Microscopy Center, Argonne)

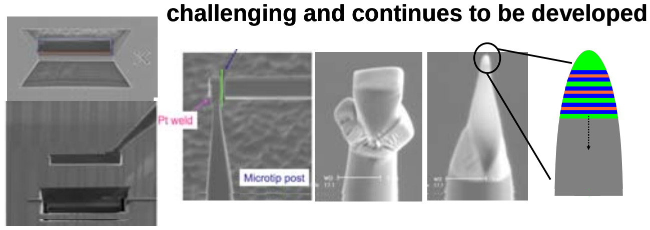
Characterization Methods

- Chemistry & structure is studied with a new laser pulsing **atom probe** (Northwestern University Center for Atom Probe Tomography)
- **Electron microscopy** is used to image structure on a micron to nanometer scale (EMC, Argonne)

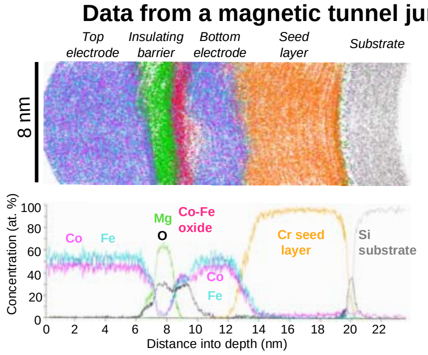
Motivation

The **nature of the interfaces** controls the properties of thin film oxide mulitlayers. **High resolution mapping** with 3D atom probe makes the direct correlation between structure, chemistry and properties possible.

Multi-step process to make needle shaped specimens is challenging and continues to be developed



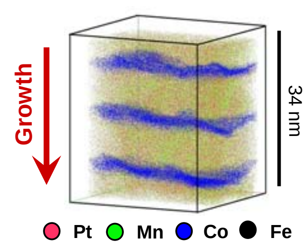
Data from a magnetic tunnel junction structure

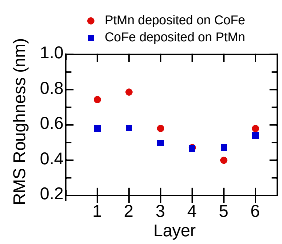


- Concentration of the top and bottom electrodes are 50 % Co and 50 % Fe
- Interfaces between layers are chemically sharp
- Evidence for a Co-Fe oxide less than 1 nm in thickness above the bottom electrode. This will influence how current passes through the layers.

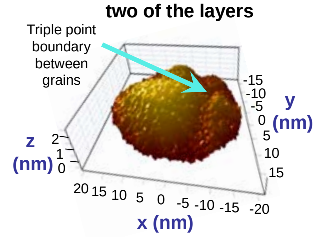
Develop a method that describes how rough the interfaces are, so we can understand thin film growth

Model PtMn (10 nm) / CoFe (3 nm) repeated structure





3-D view of the interface between two of the layers



- Well defined grooves in the interface establish the location of grain boundaries
- Fine-scale roughness is measured
- Interfacial roughness differs between alternate interfaces in early growth

Conclusions

The high resolution atom maps produced by the **atom probe** are powerful. They **let us see where atoms reside** inside materials. We demonstrate how these maps enable us on an **atomic scale and in 3-dimensions** to directly visualize very thin layers, their chemistry, what the interfaces underneath the surface look like in thin film multilayers. This allows better understanding of film growth and the relationship between structure and properties.

Future Directions

- **Other novel materials of commercial interest: ferroelectric capacitors and tunnel junctions**
- **Address how processing techniques used in companies might influence growth: to aid in the design of better films**
- **Generate realistic models on how our films behave based on the actual structure & chemistry**

More Information

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1. "Materials for Magnetic Data Storage" Materials Research Society Bulletin 31 (May 2006)
2. "Atom probe tomography" TF Kelly & MK Miller, Review of Scientific Instruments **78** (2007)
3. "In situ site-specific specimen preparation for atom probe tomography" K Thompson et al. Ultramicroscopy **107** (2007) pp. 131-139.

Interfacial Materials Group at Argonne: http://www.msd.anl.gov/groups/im/
Electron Microscopy Center at Argonne: http://www.emc.anl.gov/
NU Center for Atom Probe Tomography: http://arc.nucapt.northwestern.edu/

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